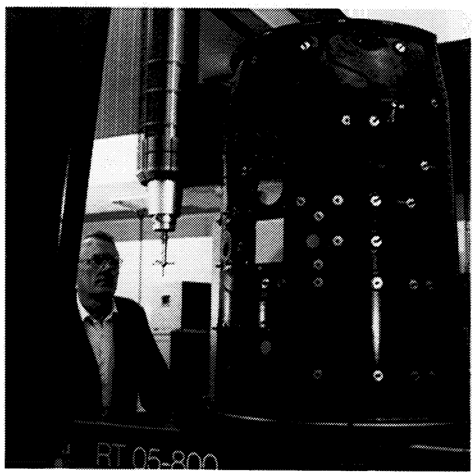
***A new type of composite material heads spinoff advances in manufacturing technology and industrial productivity***

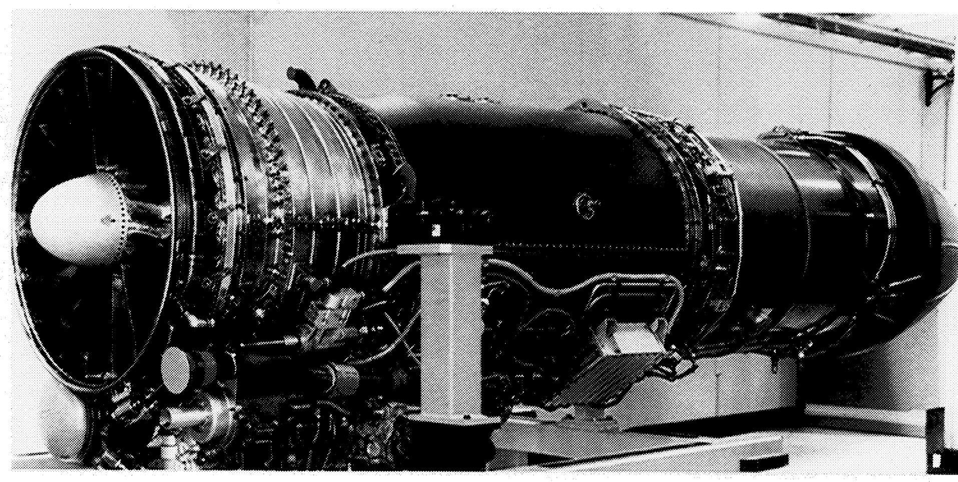
In the never-ending quest for reduced weight in all types of aerospace vehicles, designers are more and more turning their attention toward composite fiber-reinforced materials, fibers bound together in a matrix. The resultant composite is generally lighter yet stronger than the metal it supplants. Extensive research and development over the past two decades resulted in expanding use of composite components, initially in military aircraft and missiles, later in commercial jetliners, more recently in private airplanes. Polymer matrix composites are also used in a broad range of non-aerospace applications where lower weight is advantageous, such as automobiles, boats, rapid transit vehicles and a variety of sports equipment from golf clubs to racing cars.

Until now composites have been limited to uses wherein they encounter only low or moderate temperatures. This year, composite materials development takes a giant step forward with the first use of a high temperature polymer matrix composite component as a primary structural member in a production-type jet engine—General Electric Company's F404, power plant for the Navy's F/A-18 strike fighter. The composite segment is the engine's outer duct, a passageway for "bypass" air, cool air that bypasses the compressor section and is ducted toward the rear of the engine to mix with the hot exhaust gas. The mix increases engine thrust and the cooler bypass air serves as a coolant for afterburner parts that operate at very high temperatures.

The composite material replaces titanium that had to be machined to shape, then chemically milled. Its use in the outer duct trims engine weight, thus contributing to lower fuel consumption, and reduces engine cost by more than $9,000 per unit. Since the F/A-18 is scheduled for high volume production over several years, savings on that single program may run as high as $30 million—and General Electric is extending the technology to several other engine programs.

The material used in the duct is a fabric woven of Union Carbide's Thornel™ graphite fiber impregnated with a high temperature polyimide resin. Known as PMR-15, the resin was developed by Dr. Tito T. Serafini and other investigators at Lewis Research Center in response to a need for a resin capable of withstanding higher temperatures to enable a significant expansion of composite applications. Epoxy resins, the resins most widely used as composite matrix materials, have excellent mechanical properties and can be processed easily, but they are limited to applications where temperatures do not exceed 350 degrees Fahrenheit. Polymers with theoretically double the temperature resistance posed extraordinary processing difficulties. More than a decade ago the Lewis team started research toward a high temperature polyimide resin that could be readily processed. After lengthy experimentation involving alteration of the chemical nature of the resin and methods of processing it, they successfully developed PMR-15, which offers good pro-





*The engine duct at left is the first composite primary structural component qualified for use on a production jet engine. Key to its high temperature resistance is a polyimide resin formulation developed by Lewis Research Center. In the photo above, the duct is shown in place (center section) on the General Electric F404 jet engine.*

cessing characteristics and remains stable at high temperatures, thus allowing fabrication of defect-free fiber reinforced composites that can operate in an environment of 600 degrees Fahrenheit or more.

But laboratory development of the polyimide was only a milestone; it then had to be converted to a manufacturing material for cost-effective production line use. In 1979, when the Lewis work was in an advanced stage and PMR-15 began to look highly promising, General Electric's Aircraft Engine Business Group, looking for a lightweight, low cost substitute for titanium plate in the F404 engine duct, became interested. There ensued a four-year processing technology effort, jointly funded by NASA and the Navy, followed by a Navy-sponsored manufacturing technology program which resulted in a manufacturing process for use of the graphite polyimide composite. Initially clothlike in appearance, the material is cut, layered and shaped to a desired configuration, then cured in an autoclave, where the fibers and resin are molded under pressure into a component that looks metallic but weighs about 15 percent less than the predecessor titanium duct. Fabricated by General Electric's Albuquerque, New Mexico facility, the F404 composite duct was extensively ground and flight tested in 1984-85 and qualified for production line use beginning in 1986.

The PMR formulation was made available to commercial suppliers of composite materials and General Electric selected Ferro Corporation, Culver City, California to provide the "prepreg," or resin-impregnated fiber material, for the F404 duct. Other manufacturers are producing composite fabrics and tapes based on PMR-15 for a range of applications that is growing rapidly. ▲

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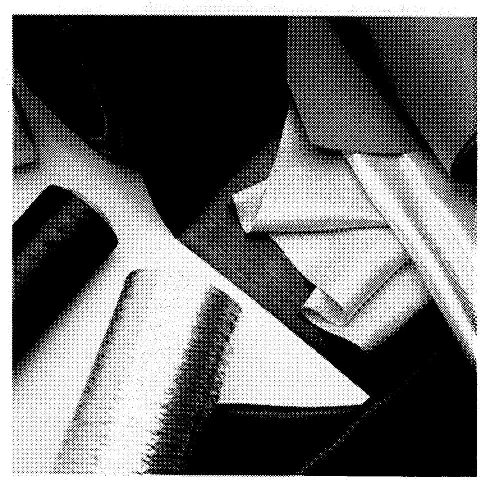

*These are samples of composite fabrics produced by Ferro Corporation, which supplied the clothlike raw material for the General Electric engine duct. The material is tailored to shape and pressure molded to become a composite duct lighter but stronger than the metal duct it replaces.*